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Perceptual and physiological responses to cycling and running in groups of trained and untrained subjects

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Summary. An interesting aspect, when comparing athletes, is the effect of *specialized* training upon both physiological performance and perceptual responses. To study this, four groups (with six individuals each) served as subjects. Two of these consisted of highly specialized individuals (racing cyclists and marathon runners) and the other two of non-specialized individuals (sedentary and all-round trained). Cycling on a cycle ergometer and running on a treadmill were chosen as modes of exercise. Variables measured included heart rate, blood lactate and perceived exertion, rated on two different scales. Results show a linear increase of both heart rate and perceived exertion (rated on the RPE scale) in all four groups, although at different absolute levels. Blood lactate accumulation, during cycling and running, differentiates very clearly between the groups. When heart rate and perceived exertion were plotted against each other, the difference at the same subjective rating (RPE 15) between cycling and running amounted to about 15-20 beats$\cdot$min^{-1} in the non-specialized groups. The cyclists exhibited almost no difference at all as compared to 40 beats$\cdot$min^{-1} for the runners. It can be concluded that specialized training changes both the physiological as well as the psychological response to exercise.

Key words: Psychophysics - Perceived exertion - Blood lactate - Cycling - Running

Introduction

The area of perceived exertion, during heavy physical work, has been studied extensively since the first experiments by Borg and Dahlström (1959, 1960) and Borg (1961, 1962). Different types of exercise have been used to induce physical strain, for example cycling, walking, running and skiing. Studies have been performed in the laboratory as well as in the field using different types of subjects, both healthy and from various patient groups. A comprehensive review of the research performed in this area has been given by Mihevic (1981), Pandolf (1983), Carton and Rhodes (1985) and Borg and Ottoson (1986).

The scientific foundation for this research was laid down by Stevens and his collaborators at Harvard (1953, 1957, 1960), who developed ratio scaling methods, thereby making it feasible to describe mathematically the relation between subjective estimates of a modality and its objective physical intensity. Stevens proposed that the psychophysical R/S relation could best be described by a power function. In its simplest mathematical form, this power function was expressed as: $R = cS^n$, where R is the perceptual intensity, c a measure constant, S the physical intensity and n the exponent. Modalities such as loudness, brightness and taste, among others, were subsequently described by these power functions (Stevens 1957, 1960, 1971; Stevens and Galanter 1957).

According to Borg (1961, 1962), power functions may also be used to describe both psychological and physiological variables during physical work. Two more constants (a and b) may then be included in the function: $R = a + c(S - b)^n$. In this general equation, a is the basic perceptual 'noise' constant, or the physiological 'rest value', which together with the physical constant b describes the starting point of the curve (or the absolute threshold R_0, S_0).

When ratio scaling methods are used, such as magnitude or ratio estimation (e.g. Stevens 1957, 1960), positively accelerating functions are found for perceived exertion, when cycling, with exponents of 1.6-1.7 (Borg and Dahlström 1959, 1960; Borg 1962).

However, one major disadvantage with psychophysical ratio methods is that they only give ratios between percepts, with no direct levels for interindividual comparisons. Furthermore, they only provide a rough mathematical description of the relations, and nothing can be said about 'absolute' intensities. In order to overcome some of these drawbacks it was necessary to develop a new method that was easy to use, yet accurate and reliable from a scientific standpoint. The result, a 15-point graded-category scale [called the rating of perceived exertion (RPE) scale; Borg 1970], made it possible for the subjects to rate the degree of perceived exertion during physical work without prior knowledge or experience.

However, since the RPE scale was constructed to increase linearly with work intensity, and thus also with heart rate (HR), it does not grow according to a psychophysically 'true' form. Previous ratio-scaling experiments have shown that the increase was positively accelerating, resulting in an exponent of about 1.6 during cycling. A new scale was therefore constructed, a scale that combines the advantages of a category scale with the psychophysically 'truer' form of a ratio scale, which was named the CR (category ratio) scale (Borg 1982; Borg et al. 1985). The two types of scales do not, however, exclude each other; they are to be seen as being complementary. The advantage with the basic RPE scale is its simplicity and ease of use, making it a perfect scale for clinical settings and other purposes where the aim is to obtain a simple, yet accurate, estimation of a person's subjective effort. The CR scale, on the other hand, has certain advantages from a researcher's standpoint.

An interesting aspect, when comparing athletes, is the difference that can be attributed to *specialized* training. It is well known that one can not excel in, for example, running through exclusive cycle training, or vice versa. Saltin (1986) points out that endurance training can be divided into two major components. A general component that aims at improving the central oxygen-transporting system, and one that develops the specific muscles involved in the activity in question. Thus, the pump capacity of the heart can be increased by a number of different activities; a strong relationship exists between pump capacity and maximal oxygen uptake. The peripheral adaptation, on the other hand, takes place in the working muscles, where an increased capillarization together with an elevated oxidative potential helps to enhance performance in the chosen activity.

The literature on the training specificity of cycling and running seems to be in agreement. With few exceptions, the training effects of cycling are seen as being more specific because of localized muscular stress (mainly the vastus lateralis muscle), resulting in peripheral adaptation (Miyamura et al. 1978; Pechar et al. 1974; Roberts and Alspaugh 1972). Faulkner et al. (1971) attributed this to the fact that the intensity and duration of muscular contraction are greater in cycling as compared to running, and, as a result, limit the blood flow in the muscle, venous return and the cardiac output. Running, which utilizes larger muscle groups, is often regarded as a more dynamic, 'total-body' activity (Kohrt et al. 1987). However, some researchers furnish evidence for a specific adaptation also during running (McArdle et al. 1978; Pannier et al. 1980).

Some interesting questions arise from the above; how do highly trained cyclists and runners perform in their chosen sport as compared to the sport they are *not* specialized in (i.e. cyclists when running and runners when cycling)? Are there physiological differences, and if so, do these result in perceptual differences as well? To make the study 'complete', a sedentary group and an all-round-trained group were included as reference groups.

Methods

The subjects for this study were 24 healthy male volunteers with a mean age of 25.5 years (range 21-33). The subjects were selected to fit into one of four groups consisting of 6 individuals/group according to their exercise habits. The four groups were as follows:

1. *Sedentary:* subjects not participating in any regular physical activity
2. *All-round trained:* subjects who participated in two or more sports on a moderate exercise level (2-4 times/week)
3. *Racing cyclists:* very good cyclists, 2 in the Swedish national team and 4 just below
4. *Marathon runners:* very good long-distance runners, with times between 2 h 21 min and 2 h 37 min on the full marathon distance.

For a physical description of the subjects, see Table 1.

The apparatus used for the tests were an electronically braked cycle ergometer (EM 369, Elema Schönander, Stockholm, Sweden), with clips so that the subject's feet could be fixed to the pedals, and a treadmill (model 24-72 Quinton, Seattle, USA). An ECG apparatus (Mingograph 61, Siemens Elema, Stockholm, Sweden) was used to record HR continuously, with the impulses coming from four electrodes taped to the subject's chest. Blood was drawn from a catheter placed in an antecubital vein to enable the collection of blood samples for subsequent spectrophotometric analysis of blood lactate concentrations, as described by Hohorst (1962). Ratings of perceived exertion were made on two different scales, the RPE scale (Borg 1970), and a CR scale with a number range from 0 to 20 and with verbal anchors placed on a numerical-ratio scale, at the locations appropriate to their quantitative meaning and with an 'absolute' 0 (Borg 1982; Borg et al. 1985). Instructions were given before each test according to a standardized procedure and written informed consent was obtained.

The tests were performed on consecutive weeks, each individual being tested once a week at the same day and hour. The subjects were randomly assigned to start with either of the two exercise modes, i.e. half of the subjects started with cycling and the other half with running. Common to both tests were work periods of 4 min, after which the exercise intensity was increased by the initial value (for cycling 50, 100, 150 W etc., and for running 3, 6, 9 $km \cdot h^{-1}$ etc.). The pedal speed on the cycle was kept constant at 60 rpm with the help of an rpm meter mounted on the handlebars; the subjects were free to choose step length/rate during the run. The exercise intensities were increased until the subjects were unable to maintain 60 rpm on the cycle or to continue on the treadmill. All measurements were obtained during the last 30 s at each intensity level, beginning with HR recording, whereafter the subjects were asked to rate their feeling of exertion on both scales. The presentation order of the RPE and the CR scale was randomized to avoid serial effects. Finally, before the intensity was increased one step, a blood sample was drawn from the subject's arm.

Table 1. Mean values (standard deviations) in age, height and body mass for sedentary and all-round-trained subjects, racing cyclists, and marathon runners

Group	n	Age (years)	Height (cm)	Body mass (kg)
Sedentary	6	26.7 (1.3)	177.3 (4.2)	71.2 (8.1)
All-round	6	25.2 (2.5)	176.5 (2.7)	67.0 (5.8)
Cyclists	6	24.2 (1.0)	179.5 (5.8)	70.8 (6.7)
Runners	6	26.0 (4.0)	180.5 (5.1)	68.3 (6.6)

Table 2. Mean values (standard deviations) of calculated estimations of physical working capacity for sedentary and all-round-trained subjects, racing cyclists and marathon runners

Group	n	Est. $\dot{V}_{O_{2max}}$ [a] ($l \cdot min^{-1}$)	Est. $\dot{V}_{O_{2max}} \cdot kg^{-1}$ [a] ($ml \cdot min^{-1} \cdot kg^{-1}$)
Sedentary	6	3.0* (0.3)	43.3* (6.3)
All-round	6	4.3** (0.2)	65.2** (6.0)
Cyclists	6	4.7 (0.4)	66.0*** (4.6)
Runners	6	5.3 (0.5)	75.2 (2.8)

[a] Estimated oxygen uptake (Est. $\dot{V}_{O_{2max}}$); estimated oxygen uptake, adjusted for body mass (Est. $\dot{V}_{O_{2max}} \cdot kg^{-1}$)
* Sedentary < all-round, cyclists, runners ($P<0.05$)
** Allround < runners ($P<0.05$)
*** Cyclists < runners ($P<0.05$)

In the statistical treatment, arithmetic means were used for all calculations. The linear regression analyses were performed according to the least-square method. Power functions were calculated according to the method described by Borg (1961, 1962). The cardiorespiratory data (in Table 2) were analysed using standard procedures for analysis of variance.

Results

An estimation of the physical working capacity in the groups is given in Table 2. These are all based on the cycle test and calculated according to the method described by Åstrand (1952) and Åstrand and Ryhming (1954).

It can be seen that the highest values are obtained by the runners, while the values for the sedentary group lie significantly below the others ($P<0.05$). The estimated $\dot{V}_{O_{2max}}$ did *not* differ significantly between the cyclists and the runners. However, this changed when the subject's body mass was included in the calculations; thus the estimated $\dot{V}_{O_{2max}} \cdot kg^{-1}$ differed significantly ($P<0.05$) between the cyclists and the runners.

Figures 1–6 graphically present the results obtained. Where appropriate, linear regression equations and power functions are shown in the figure legends. Test sessions were terminated when subjects no longer were able to maintain 60 rpm on the cycle or to continue on the treadmill. Terminal intensities did, therefore, vary between the groups and became, on the cycle ergometer, 200 W for the sedentary and 250 W for the all-round-trained subjects, and 300 W for the cyclists and the runners. The groups ended treadmill running at velocities of 15 $km \cdot h^{-1}$ (sedentary and all-round-trained), 18 $km \cdot h^{-1}$ (cyclists), and 21 $km \cdot h^{-1}$ (runners). Occasionally, one or two subjects in each group were able to complete one intensity level more than the others. However, values shown are for the last intensity that *all* subjects in the respective groups were able to finish.

Perceived exertion

Perceived exertion, rated on the RPE scale, increased with the exercise intensity in a linear fashion in all four

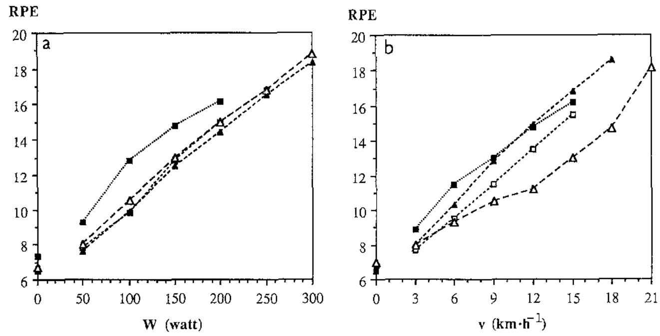

Fig. 1. a Relations between rating of perceived exertion (*RPE*) values and power (*W*) during cycling. Linear regression: ■, $RPE=7.3+0.049W$ (0.999); □, $RPE=5.5+0.046W$ (0.997); ▲, $RPE=5.7+0.043W$ (0.998); △, $RPE=6.2+0.428W$ (0.998). **b** Relations between RPE values and velocity (v) during running. Linear regression: ■, $RPE=7.5+0.597v$ (0.993); □, $RPE=5.7+0.653v$ (0.999); ▲, $RPE=6.1+0.711v$ (0.998); △, $RPE=5.9+0.515v$ (0.975). ···■··· sedentary; ---□--- all-round; ---▲--- cyclists; --△-- runners

groups during cycling. As could be expected, the sedentary group consistently rated their exertion much higher than did the other groups at comparable work rates.

Also during running (Fig. 1b) the perceived exertion ratings did increase in a linear fashion, the runners being a slight exception, although the four groups reacted more heterogeneously during running as compared to cycling. The difference in perceived exertion between the runners and the cyclists was also much more pronounced during running.

Pre-test ratings did not, however, vary much between the groups, neither during cycling nor running (6.5–7.3).

The CR ratings, made during the cycle test, varied according to positively accelerating functions with exponents between 2.2 and 2.4. These are somewhat higher than previously found (1.6–1.7). The sedentary group was again separated from the other three groups, who were very close together.

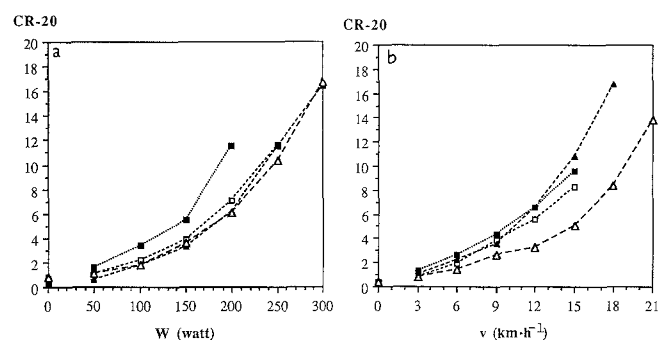

Fig. 2. a Relations between ratings on the category-ratio (*CR*) scale and power (*W*) during cycling. Power functions: ■, $CR=1.2+5.46\times10^{-5}W^{2.3}$ (0.997); □ $CR=0.8+5.29\times10^{-5}W^{2.2}$ (0.999); ▲, $CR=0.3+5.33\times10^{-5}W^{2.2}$ (0.999); △, $CR=1.0+1.33\times10^{-5}W^{2.4}$ (0.999). **b** Relations between ratings on the CR scale and velocity (v) during running. Power functions: ■, $CR=0.7+0.096v^{1.7}$ (0.999); □, $CR=0.3+0.075v^{1.7}$ (0.999); ▲, $CR=0.7+0.027v^{2.2}$ (0.998); △, $CR=0.7+8.23\times10^{-3}v^{2.4}$ (0.994). For explanation of symbols, see Fig. 1

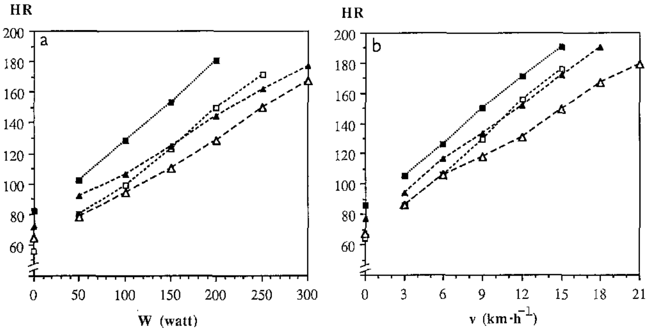

Fig. 3. **a** Relations between heart rate (HR, in beats·min^{-1}) and power (W) during cycling. Linear regression: ■, $HR = 75.5 + 0.524W$ (0.999); □, $HR = 54.7 + 0.466W$ (0.999); ▲, $HR = 72.9 + 0.350W$ (0.999); △, $HR = 58.1 + 0.361W$ (0.999). **b** Relations between heart rate (HR, in beats·min^{-1}) and velocity (v) during running. Linear regression: ■, $HR = 83.9 + 7.167v$ (0.999); □, $HR = 61.9 + 7.667v$ (0.999); ▲, $HR = 76.1 + 6.352v$ (0.999); △, $HR = 72.0 + 5.143v$ (0.998). For explanation of symbols, see Fig. 1

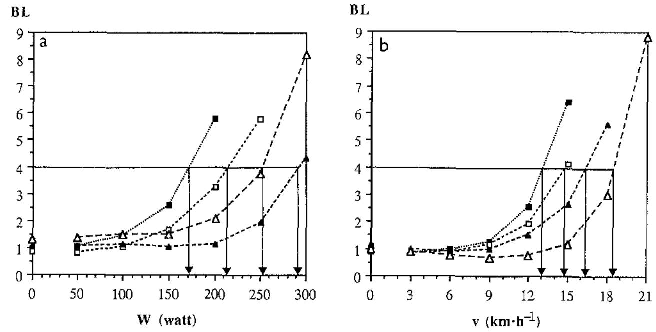

Fig. 4. **a** Relations between blood lactate accumulation (BL, in mmol·l^{-1}) and power (W). Power functions: ■, $BL = 0.99 + 6.16 \times 10^{-8} W^{3.4}$ (0.999); □, $BL = 0.80 + 2.86 \times 10^{-8} W^{3.4}$ (0.999); ▲, $BL = 1.10 + 1.53 \times 10^{-4} (W - 190)^{2.1}$ (0.999); △, $BL = 1.49 + 4.69 \times 10^{-5} (W - 140)^{2.3}$ (0.999). **b** Relations between blood lactate accumulation (BL, in mmol·l^{-1}) and velocity (v). Power functions: ■, $BL = 0.84 + 1.34 \times 10^{-4} v^{3.8}$ (0.996); □, $BL = 0.82 + 1.43 \times 10^{-4} v^{3.6}$ (0.991); ▲, $BL = 0.96 + 2.02 \times 10^{-2} (v - 8)^{2.3}$ (0.999); △, $BL = 0.75 + 9.15 \times 10^{-3} (v - 11)^{2.9}$ (0.998). For explanation of symbols, see Fig. 1

The CR ratings, during running, were similar in three of the groups with the exception of the runners, who rated their exertion considerably lower at comparable speeds. Their initially low ratings accelerated towards the end, resulting in an exponent of 2.4. The cyclists' steadier increase gave them a slightly lower exponent (2.2).

Heart rate

During cycling, the HR increase was very linear in all four groups resulting in correlation coefficients around 0.999.

The HR increase, during running, was also almost linear in all four groups although the realtively high initial HR of the runners increased more slowly than that of the others during the latter part of the test.

Blood lactate

Blood lactate accumulation, during cycling, started immediately at the beginning of exercise in the sedentary group and slightly later in the all-round-trained group. The form of the growth functions in the two groups was almost identical however, and could best be described by power functions with exponents of 3.4. The change for the cyclists and the runners was different and the lactate levels for the first three loads even decreased somewhat (non-significantly). This made the inclusion of b-values necessary to describe the functions properly (140 W for the runners and 190 W for the cyclists). As a result, the exponents are between 2.1 and 2.3. The terminal blood lactate value for the runners was almost twice as high as that of the cyclists (8.20 vs 4.34 mmol·l^{-1} at 300 W). W_{OBLA} values (OBLA, onset of blood lactate accumulation) ranged from 172 W for the sedentary group, 212 W for the all-round-trained, 252 W for the runners, up to 292 W for the cyclists.

Blood lactate accumulation, during running, started very late for the group of runners. In fact, their lactate concentration decreased to some extent (non-significantly) until 9 km·h^{-1}, after which it started to increase slowly up to 15 km·h^{-1}, whereafter a rapid increase took place. The cyclists showed the same pattern with an initial, non-significant decrease, after which the increase started. This made it necessary to include b-values in the power functions (8 and 11 km·h^{-1} respectively). The observation from Fig. 4a is reversed in this case: now the cyclists reached lactate levels nearly twice as high as those of the runners at the last common level, i.e. 18 km·h^{-1} (5.59 vs 3.00 mmol·l^{-1}), although the runners were also able to finish a 4-min run at 21 km·h^{-1}, reaching a terminal lactate level of 8.82 mmol·l^{-1}. v_{OBLA} values varied between velocities of 13.1 km·h^{-1} for the sedentary group, 14.8 km·h^{-1} for the all-round-trained group, 16.3 km·h^{-1} for the cyclists, and 18.5 km·h^{-1} for the group of runners.

In order to compare the relationship between the dependent variables HR and RPE in greater detail, these were plotted against each other (Fig. 5a–d). The sedentary and the all-round-trained group exhibited, at the RPE 15 level, a difference between cycling and running of about 15–20 beats·min^{-1}. The cyclists showed hardly any difference at all in HR at the RPE 15 level, whereas the runners' difference amounted to about 40 beats·min^{-1}.

This is further exemplified in Fig. 6 where RPE values from the cycle test were plotted against RPE values from the treadmill test. This was accomplished by simply calculating the respective RPE rating at several pre-determined HR values (100, 120, 140, 160 and 180 beats·min^{-1}) for each exercise mode. If one regards the all-round-trained group as the 'normal' – or average – for non-specialized individuals, one finds that the cyclists and runners end up on separate 'sides'.

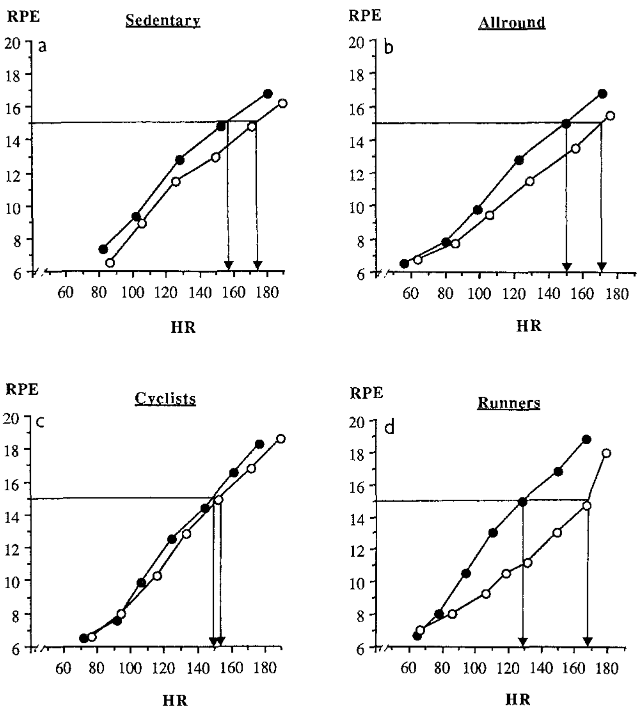

Fig. 5. a–d. A comparison between cycling and running, with heart rate (*HR*) on the *x*-axis and RPE on the *y*-axis, in the four groups. —●— cycling; — — running

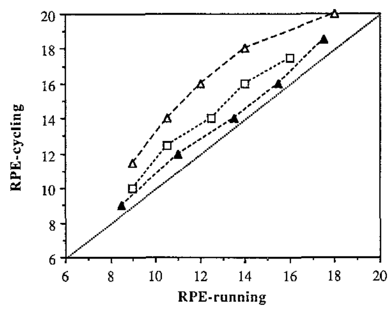

Fig. 6. RPE values from the cycle test plotted against RPE values from the treadmill test, for all-round-trained subjects, cyclists and runners. For explanation of symbols, see Fig. 1

Discussion

The results of this study show that there are similarities as well as differences between the four groups in regard to perceptual and physiological reactions over intensity and time. Generally, the use of power functions with the form $R = a + c(S - b)^n$ worked well to describe mathematically the increase in all variables. The analysis of variance revealed no statistically significant difference in estimated $\dot{V}_{O_{2\,max}}$ (Table 2) between the cyclists and the runners. However, when body mass was included in the calculation (estimated $\dot{V}_{O_{2\,max}} \cdot kg^{-1}$), the difference became significant ($P < 0.05$). Since the $\dot{V}_{O_{2\,max}}$ values shown were *estimated* from the cycle test, it can be assumed that the cyclists' estimated $\dot{V}_{O_{2\,max}}$ reflects their 'true' maximal oxygen uptake to a higher degree than does the runners'. Glassford et al. (1965), while comparing four different tests of maximal oxygen uptake through both predicted and actual methods, noted that the question of local muscular fatigue cannot be ignored. Reportedly many of the subjects – who were unaccustomed to cycling – complained that the excess pedalling during the cycle test caused extreme fatigue in the legs with only moderate stress in the upper body. Glassford et al. concluded that this extreme fatigue in a very limited muscle area might be too local to elicit as great a response from the cardiovascular/respiratory system as does the more general fatigue of treadmill running. This assumption is strengthened by Rodahl (1960), who attributed this to the inability of a non-specialized subject to load the circulation fully because of muscular insufficiency. Further 'proof' for the correctness of this assumption can, in this study, be found in the fact that, although the runner's HR consistently were lower than those of the cyclists throughout the cycle test, their blood lactate accumulation was much more rapid especially at higher intensities. At the final intensity (300 W) the runners' HR was 10 beats $\cdot$ min^{-1} *less* than that of the cyclists (167 vs 177 beats $\cdot$ min^{-1}), whereas the blood lactate concentration was nearly *twice as high* (8.20 vs 4.34 mmol $\cdot$ l^{-1}). There also seem to be 'inherent' differences in maximal working capacity between various groups of trained athletes. Saltin and Åstrand (1967), while comparing among others the Swedish national teams in bicycling and long-distance running, found that elite runners generally obtained higher $\dot{V}_{O_{2\,max}} \cdot kg^{-1}$ than elite cyclists (mean measured values were 79 ml $\cdot$ min^{-1} $\cdot$ kg^{-1} for the runners vs 74 ml $\cdot$ min^{-1} $\cdot$ kg^{-1} for the cyclists). A similar finding was published by Verstappen et al. (1982).

All in all, the significant difference obtained in this study between the estimated $\dot{V}_{O_{2\,max}} \cdot kg^{-1}$ of the cyclists and the runners seems to be in accordance with what could be expected and should therefore not unduly influence the interpretation of the results. Instead, it might be interpreted as showing that maximal oxygen uptake only reflects a kind of 'general fitness' and that blood lactate concentration, in relation to work rate, is a far better indicator of actual physical working capacity in specifically trained athletes.

A detailed discussion of the differences found between the groups is given below.

Perceived exertion

Since the RPE scale was developed to grow in a linear way with power in cycling (and thus also with HR), a linear relation was expected. This was also found, although it is interesting to note that the levels for the three groups of trained individuals are much the same, with the sedentary group quite separate from the rest (Fig. 1a). This was not as pronounced when running (Fig. 1b), although a linear relationship exists, the group of runners being a slight exception.

The obtained exponents for perceived exertion, rated on the CR scale, was slightly above those that Borg (1962, 1972) found when using ordinary ratio scales (1.6–1.7), although they are well in accordance with the ones obtained by Borg et al. (1987), i.e. just above 2. The exponents for running were slightly lower and ranged between 1.7 and 2.4.

It is clear that the ratings of perceived exertion obtained reflect the fitness levels of the various groups, i.e. the sedentary group perceive both cycling and running to be relatively more strenuous than the other groups at comparable work intensities. It is also natural to find that the cyclist group rate cycling to be the least strenuous and that the runners feel the same way about running. This shows the value and importance of specialized training and the following ease with which the athletes perform their chosen sport. However, even larger subjective differences were expected to be found between the cyclists and the runners as a result of their specialized training. A possible explanation for the relatively small difference in ratings, is that the subjects were asked to rate their *overall* feeling of exertion. Had they been asked to differentiate between the exertion in the legs and in the upper body (breathing, pulse, etc.) the picture might have been slightly different, in the light of the observed differences in blood lactate accumulation, which might have influenced the magnitude of local fatigue ratings (i.e. legs) to a greater extent than it did the overall ratings of exertion.

Heart rate

That HR increases in a linear way against power while cycling is a well-known fact. It is interesting to note, however, that the earlier-mentioned 'level differences' between the groups in perceived exertion (Fig. 1a) are equally clear when HR is measured (Fig. 3a). While running the HR also increases in a linear way, the results for the runners again being somewhat less linear (Fig. 3b). This is probably explained by the initially low speeds that precluded an economic running style, thereby increasing the HR and, consequently, the perceived exertion.

Perceived exertion vs heart rate

It is usual to find a difference in HR, at the *same* level of perceived exertion, when cycling and running are compared. Running usually exhibits higher HRs than does cycling at the same subjective intensity. The magnitude of this difference is normally in the approximate range of 15–20 beats$\cdot$min^{-1} at the RPE 15 level (e.g. Borg et al. 1987). This was also found for the sedentary and the all-round-trained group. The reason for this difference can, most likely, be attributed to the fact that running utilizes relatively larger muscle masses than cycling. The more intense use of relatively smaller muscle masses during cycling results in a higher rating of perceived exertion, even though the HRs are comparably lower. The cyclists, being unused to running, do not show this difference (Fig. 5c). They perceive cycling and running to be almost equally straining at a HR of about 150 beats$\cdot$min^{-1}. As for the runners (Fig. 5d), they already report a rating of 15 at a HR of about 130 beats$\cdot$min^{-1} during cycling, whereas their HR reaches almost 170 beats$\cdot$min^{-1} during running. This is further shown in Fig. 6, where it can be noted that the cyclists and runners fall on both sides of the all-round-trained group, who can be considered as the 'average' for non-specialized individuals.

Blood lactate

The blood lactate accumulation distinguishes very well between the differently trained groups, as has been noted above. Accordingly, it is the cyclists that show the slowest accumulation while cycling, as well as the lowest terminal value. The difference from the other groups could have been even larger if the cyclists had been allowed to pedal faster than 60 rpm. They felt this to be too slow and therefore less 'economic' than a faster speed would have been. This might also explain why the cyclists were unable to finish a complete work period on 350 W, since neither their HR's nor their blood lactate concentrations were excessively high at 300 W.

When calculating power functions it has been necessary to include b-values both for the cyclists and runners, because of the initial decrease (Fig. 4a, b). The magnitude of these b-values, for cycling, are higher than those found in an earlier study by Borg et al. (1987). However, this is explained by the use of *very* well trained cyclists and runners in this study, as compared to the all-round-trained subjects they used. The resting lactate values (a-values in the power functions) are all around 1 mmol$\cdot$l^{-1}, which can be considered normal. The observed decrease in lactate concentration during the first work intensities, for the cyclists and runners, is a common finding and it merely shows the ability of their bodies to take care of the lactic acid in an effective way.

The group's OBLA is also shown in Fig. 4a, b; this was done in order to give further possibilities of comparisons. The 'OBLA-point' refers to the point where the blood lactate concentration reaches 4 mmol$\cdot$l^{-1} and is considered to represent the limit between exercise intensities that are predominantly aerobic vs anaerobic in their nature. The OBLA concept in itself has been disputed since it was introduced by Sjödin and Jacobs (1981). Some critics argue that it is difficult to establish a well-defined 'break-point', and that the work rate at which a non-linear increase in ventilation occurs need not be at the same work rate at which the lactate concentration increases (e.g. Green et al. 1983). This, however, does not invalidate the concept as a whole, according to Åstrand and Rodahl (1986), since it still provides important information about the aerobic potential of the individual. Some researchers propose another threshold, like 2.5 mmol$\cdot$l^{-1}, or even regard a 10% increase as a kind of threshold etc. Regardless of method, the *relative* differences remain stable between the four groups in this study, clearly indicating an effect of specialized training.

Conclusion

This study has shown many similarities between the three groups in which physically active individuals were included. However, both the blood lactate accumulation and the subjective ratings of perceived exertion differentiate very clearly between the athletes and the sports they have specialized in. Taken together, a natural conclusion would be that *both* cycling and running exercise result in a general training effect as well as a specific training effect.

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